CROPPING SYSTEMS

Effects of Western Corn Belt Cropping Systems on Agroecosystem Functions

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ABSTRACT

Agricultural sustainability is enhanced by management practices that optimize the performance of multiple agroecosystem functions. The performance of western Corn Belt cropping systems was evaluated based on four agroecosystem functions: food production, raw materials production, nutrient cycling, and greenhouse gas regulation. A simple multiattribute ranking procedure was used to quantify agroecosystem performance using data from a long-term cropping systems experiment near Mead, NE. Treatments included in the procedure were continuous corn (*Zea mays* L.) (CC), corn–soybean [*Glycine max* (L.) Merr.] (C–SB), corn–oat (*Avena sativa* L.) + clover [80% sweet clover (*Melilotus officinalis* L.) and 20% red clover (*Trifolium pratense* L.)]–sorghum [*Sorghum bicolor* (L.) Moench]–soybean (C–OCL–SG–SB), and corn–soybean–sorghum–oat + clover (C–SB–SG–OCL) each at three N fertilization levels (ZERO, LOW, and HIGH). Based on treatment averages of soil and crop indicators from 1983 to 1998, agroecosystem performance scores ranged from 66.6 to 77.3, with a least significant difference (LSD) between treatments of 2.2 ($P < 0.05$). Treatments with the highest scores included C–OCL–SG–SB/LOW (77.3), C–SB/LOW (76.9), CC/LOW (76.7), CC/HIGH (76.6), and C–SB–SG–OCL/LOW (75.3). Among these treatments, those fertilized at the LOW N rate attained high scores through moderate performance in all four agroecosystem functions. The CC/HIGH treatment, however, attained a high score solely through its superior capacity to be highly productive, as its scores for the two environmental quality–related functions were the lowest among all treatments. Correlations between production- and environmental protection–related functions were negative, emphasizing the importance of employing management practices that are productive yet minimize deleterious environmental impacts.

Cropping systems perform multiple functions in their role as agroecosystems. In addition to food, feed, and fiber production, cropping systems cycle nutrients, influence water partitioning within landscapes, and regulate greenhouse gas flux, thereby influencing environmental quality as well as human and animal health (Costanza et al., 1997; Daily et al., 1997). The long-term viability of cropping systems—or any agricultural production system for that matter—is largely determined by how well these functions are executed within the context of the production, economic, and resource conservation goals of agricultural producers. Consequently, quantifying the effects of management practices on agroecosystem functions is necessary to determine the sustainability of cropping systems.

Performance-based indices have been used to assess the effects of management practices on agroecosystem functions (Andrews et al., 2001; Glover et al., 2000; Ericksen and McSweeney, 1999; Karlen and Stott, 1994). These indices use expert opinion or principal-component analysis to select indicators representative of specific functions. Once selected, the indicators are scored based on their relative difference from a standard or optimum value using either linear or nonlinear techniques. Scores within agroecosystem functions are typically summed across functions, taking into consideration the relative importance of each function within the context of climatic, geographical, and socioeconomic conditions (Edwards and Newman, 1982; Stillwell et al., 1981).

A simplified multiattribute ranking procedure using a linear scoring technique was developed by Liebig et al. (2001) to determine agroecosystem performance for treatments in long-term experiments. The procedure was successful in discriminating between conventional and alternative cropping systems when agroecosystem performance was based on functions of food production, raw materials production, nutrient cycling, and greenhouse gas regulation. Given the demonstrated utility of the procedure to quantify the environmental dimension of agricultural sustainability, a more in-depth evaluation of its use is warranted. In this study, we sought to use the procedure to determine agroecosystem performance of four corn-based crop sequences (CC, C–SB, C–OCL–SG–SB, and C–SB–SG–OCL) each at three N fertilization levels for a long-term cropping systems experiment in the western Corn Belt.

MATERIALS AND METHODS

Site Description

Data for this evaluation were used from a cropping systems experiment established in 1983 on the Agronomy Farm at the University of Nebraska Agricultural Research and Development Center, approximately 6 km south of Mead, NE, in Saunders County (41°10′ N, 96°25′ W). The research site is on Peoria-age loess with nearly level topography (0–3% slope). The predominant soil is Sharpsburg silty clay loam (fine, smectitic, mesic Typic Argiudoll).

The cropping systems study consisted of seven crop sequences (three monocultures, two 2-yr rotations, and two 4-yr rotations) and three rates of N fertilizer (Varvel, 1994). Corn-based cropping sequences included in the study were CC,

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Abbreviations: CC, continuous corn, C–OCL–SG–SB, corn–oat + clover–sorghum–soybean; C–SB, corn–soybean; C–SB–SG–OCL, corn–soybean–sorghum–oat + clover; HIGH, high N fertilization level; LOW, low N fertilization level; ZERO, zero N fertilization.

C–SB, C–OCL–SG–SB, and C–SB–SG–OCL. The oat and clover intercrop represented a single year in each 4-yr sequence. Oat was harvested during the first year while the clover was allowed to continue to grow into the fall. Crop sequence treatments were considered whole plots and assigned to an area of 9 by 32 m. Subplots (9 by 10 m) were assigned within each whole plot, each differing by N application rate. Nitrogen rates were 0, 90, and 180 kg N ha^{-1} for corn and grain sorghum and 0, 34, and 68 kg N ha^{-1} for soybean and oat + clover. Nitrogen was applied as a broadcast application of NH_4NO_3 in the spring of each year. Each phase of every crop sequence occurred every year, and treatment combinations were replicated five times.

Cultural practices used in the study were similar to those of local producers. Crop residue from corn and grain sorghum was shredded in late fall. Clover was killed with a tandem disk in mid-April when weather permitted. Tillage was conducted on all plots in the spring and usually consisted of disking once or twice 10 to 15 cm deep followed by harrowing just before planting. Details on other management practices with respect to planting, weed control, and harvesting are reviewed elsewhere (Varvel, 1994).

Treatments and Data

Long-term averages of crop and soil indicators used in the multiattribute ranking procedure were determined for the four corn-based crop sequences at the three N application rates. Data from 1983–1998 were used, representing four complete cycles of the 4-yr crop sequences. Indicators included in the procedure were grain and stover yield, grain and stover N uptake, residual (postharvest) soil NO_3–N, early-spring soil NO_3–N, soil pH, and soil organic C. Indicators were averaged across each crop phase within the four crop sequences.

Detailed background on data collection methods for crop and soil indicators is provided by Varvel (1994), Varvel and Peterson (1990), and Peterson and Varvel (1989). Briefly, dry matter samples were collected each year when crops were at physiological maturity. Representative plants from each plot were cut, weighed, dried, and threshed for grain. Ground subsamples of grain and stover were analyzed for total N (Kjeldahl before 1990 and dry combustion thereafter). Residual soil NO_3–N reflected postharvest NO_3–N levels over the 0- to 183-cm depth (by summing the averages of 30.5-cm-depth increments to 183 cm) from four composited cores (5.0 cm i.d.) collected in each plot. Surface soil samples (0–30.5 cm) for early-spring soil NO_3–N, soil pH, and soil organic C were collected by compositing 15 cores (1.8 cm i.d.) in each plot. All soil samples were air-dried and ground after collection. Soil NO_3–N was estimated from 1:10 soil/KCl (2 *M*) extracts using Cd reduction followed by a modified Griess–Ilosvay method (Mulvaney, 1996). Soil pH was estimated from a 1:1 soil/water mixture (Eckert, 1988). Soil organic C was determined by dry combustion. Organic C was considered the same as total C as carbonates were not present at 30.5 cm. Data for soil NO_3–N and soil organic C were converted to a volumetric, oven-dry basis by sampling depth using field-measured soil bulk density (Blake and Hartge, 1986).

Data for crop indicators were complete from 1983–1998, except for 1983 when only data on grain yield were collected. Data for residual soil NO_3–N were collected at the end of each 4-yr rotation cycle (1986, 1990, 1994, and 1998). Evaluation of indicators from surface soil was variable over time. Early-spring soil NO_3–N was evaluated from 1984–1991 and in 1994, 1996, and 1998. Soil pH was evaluated in 1994 and 1998, and soil organic C was evaluated in 1984, 1991, 1994, and 1998.

Calculation of Agroecosystem Performance Scores

The procedure used to determine agroecosystem performance followed four basic steps: data grouping, calculation of averages, ranking and scoring treatments, and summing of scores within and across agroecosystem functions. A thorough description of the procedure is outlined by Liebig et al. (2001); only a synopsis of the procedure will be presented here.

Indicators included in the procedure were categorized into four agroecosystem functions following general guidelines presented by Costanza et al. (1997). Functions and associated indicators were (i) food production (grain yield and grain N uptake), (ii) raw materials production (stover yield and stover N uptake), (iii) nutrient cycling (residual soil NO_3–N and soil pH), and (iv) greenhouse gas regulation (soil organic C and early-spring soil NO_3–N). The relative importance of each agroecosystem function on agricultural sustainability was considered to be the same. Consequently, they were given equal weight within the calculation procedure:

$$\begin{aligned}\text{Agroecosystem performance} = f[&(\text{food production} \times W_{fp}), (\text{raw materials production} \times W_{rmp}),\\ &(\text{nutrient cycling} \times W_{nc}),\\ &(\text{greenhouse gas regulation} \times W_{ggr})]\end{aligned} \quad [1]$$

where W_{fp}, W_{rmp}, W_{nc}, and W_{ggr} are the relative weights given to food production, raw materials production, nutrient cycling, and greenhouse gas regulation, respectively (all 1.0).

Averages of crop and soil indicators were calculated from 1983–1990, 1983–1994, and 1983–1998, resulting in averages covering the second, third, and fourth rotation cycles of the 4-yr crop sequences. In the case of soil pH and soil organic C, averages over time were not calculated due to their cumulative effects on agroecosystem performance. Instead, point-in-time measurements in 1991 (soil organic C only) and 1994 and 1998 (soil pH and soil organic C) were selected to be associated with the 1983–1990, 1983–1994, and 1983–1998 averages, respectively.

Averaged treatment values were ranked for each indicator in ascending or descending order, depending on whether a higher value for the indicator was considered good or bad with respect to enhancing agricultural sustainability. For ranking to occur, the following assumptions were made for the food production, raw materials production, nutrient cycling, and greenhouse gas regulation functions, respectively: (i) higher values for grain yield and grain N uptake were considered to enhance agricultural sustainability; (ii) higher stover yield and stover N uptake were considered to do the same; (iii) lower levels of residual soil NO_3 in the 0- to 183-cm depth after harvest were considered to reflect more efficient nutrient uptake by crops, and a value of 7.0 for soil pH was established as an optimum for nutrient cycling, based on knowledge of row-crop performance in the western Corn Belt as well as pH-dependent biological processes tied to nutrient cycling efficiency (Patriquin et al., 1993; Smith and Doran, 1996); and (iv) higher values for soil organic C represented reduced loss of soil C to the atmosphere while lower levels of early-spring soil NO_3 represented decreased potential for N_2O emissions from denitrification.

Once ranked, treatments were scored based on their relative difference from the optimal value using a linear scoring technique. For data arranged in descending order, the highest treatment value (considered optimal) was assigned a score of 1.0. Remaining treatment values were scored based on their relative difference from the highest treatment value. For treatments arranged in ascending order (where a lower value is considered more optimal), the lowest treatment value was assigned a score of 1.0 while the remaining treatments were scored based on their relative difference from the value of that treatment. For soil pH, treatments were scored based on their relative difference from the optimal value of 7.0 (e.g., pH = 6.0; score = 6.0/7.0 = 0.86).

The relative performance of treatments within agroecosystem functions was determined by summing indicator scores within functions. Indicators were considered to possess equal importance with regard to their impact on agroecosystem functions. As a result, indicators were scored by assigning the same relative weight to all indicators in the calculations (all 1.0). For the 1983–1990 time period, however, scores for residual soil NO_3–N were multiplied by 2 within the nutrient-cycling function because of a lack of soil pH data for that period. On summing scores within agroecosystem functions, scores were summed across functions. The final score reflected a relative ranking of overall agroecosystem performance among treatments for functions included in the procedure. Scores were scaled to 100 to express them in a more familiar context.

Crop sequence and N fertilization effects on crop and soil indicators were evaluated using an appropriate split-plot model in PROC MIXED for each time period (Littell et al., 1996). Replication and its interaction with crop sequence were considered random effects. Because the 12 treatments were ranked together during the scoring procedure, scores for individual indicators, agroecosystem functions, and overall performance were evaluated with treatments considered as individual production systems. Scored variables were tested for normality using the Kolmogorov–Smirnov test within PROC UNIVARIATE (SAS Inst., 1990). Most variables were normally distributed; therefore, treatments were compared using LSD at $P < 0.05$ in PROC MIXED.

Table 1. Summary of *P* values for analysis of variance using PROC MIXED, showing main and interactive effects of crop sequence and N rate on indicators used to represent agroecosystem functions for averages from 1983–1990, 1983–1994, and 1983–1998.

Indicator	Source of variation: Sequence	N rate	Sequence × N rate
	1983–1990		
Grain yield	<0.0001	<0.0001	<0.0001
Grain N uptake	<0.0001	<0.0001	<0.0001
Stover yield	0.0007	<0.0001	0.0011
Stover N uptake	<0.0001	<0.0001	<0.0001
Residual soil NO_3–N	0.0098	<0.0001	<0.0001
Soil pH	–	–	–
Soil organic C†	0.4213	0.9071	0.6676
Early-spring soil NO_3–N	0.2212	<0.0001	0.0628
	1983–1994		
Grain yield	<0.0001	<0.0001	<0.0001
Grain N uptake	<0.0001	<0.0001	<0.0001
Stover yield	<0.0001	<0.0001	<0.0001
Stover N uptake	<0.0001	<0.0001	<0.0001
Residual soil NO_3–N	0.0333	<0.0001	<0.0001
Soil pH	0.0136	<0.0001	0.1326
Soil organic C	0.2412	0.1649	0.4825
Early-spring soil NO_3–N	0.2703	<0.0001	0.0129
	1983–1998		
Grain yield	<0.0001	<0.0001	<0.0001
Grain N uptake	<0.0001	<0.0001	<0.0001
Stover yield	<0.0001	<0.0001	<0.0001
Stover N uptake	<0.0001	<0.0001	<0.0001
Residual soil NO_3–N	0.1262	<0.0001	<0.0001
Soil pH	0.5507	<0.0001	0.0132
Soil organic C	0.1647	0.9758	0.4078
Early-spring soil NO_3–N	0.0503	<0.0001	0.0002

† Soil organic C data from 1991 was used to represent the 1983–1990 time period.

RESULTS AND DISCUSSION

Treatment Effects on Crop and Soil Indicators

Crop sequence and N fertilization treatments had a significant effect on crop and soil indicators (Table 1). Crop sequence affected grain yield, grain N uptake, stover yield, and stover N uptake during each time period. Crop sequence also affected residual soil NO_3–N over the 1983–1990 and 1983–1994 time periods and soil pH in 1994. Only soil organic C and early-spring soil NO_3–N were not affected by crop sequence at $P < 0.05$. Nitrogen rate significantly affected all indicators except soil organic C during each time period. The number of significant interactions increased over time, such that seven of the eight indicators possessed significant crop sequence × N rate effects over the 1983–1998 time period.

Trends in crop and soil indicators among treatments were similar during each time period. As a result, treatment averages of indicators for 16 yr (1983–1998) are presented (Table 2). Nitrogen fertilization had a strong positive effect on grain and stover yield, grain and stover N uptake, residual soil NO_3–N, and early-spring soil NO_3–N as shown by significant increases in each indicator when averaged across crop sequence. Soil pH was also affected by N rate, but values decreased with increasing N rate.

Significant effects of crop sequence were limited to aboveground indicators. Grain and stover yield were significantly greater in CC compared with other crop sequences when averaged across N rate. Order among crop sequences for grain and stover yield was CC > C–SB = C–OCL–SG–SB > C–SB–SG–OCL and CC > C–OCL–SG–SB > C–SB–SG–OCL = C–SB, respectively. Relative differences in grain N uptake among crop sequences were substantial (range = 69.9–116.2 kg ha^{-1}) and followed the order of C–SB > C–OCL–SG–SB > C–SB–SG–OCL > CC, with each crop sequence significantly different from the others. Stover N uptake was also significantly different at each crop sequence, with an order of C–OCL–SG–SB > C–SB–SG–OCL > CC > C–SB (Table 2).

The strong effect of N fertilization on crop and soil indicators was expected as N fertilizer is known to influence plant productivity, soil N dynamics, and surface soil condition (Stevenson, 1982; Varvel and Peterson, 1990; Bouman et al., 1995; Varvel, 1994; Yamoah et al., 1998). Among crop sequences, inclusion of corn resulted in greater grain and stover yield, whereas inclusion of soybean tended to do the opposite. The difference in grain and stover yield between the 4-yr sequences was likely caused by lower soil water status in C–SB–SG–OCL. Peterson and Varvel (1989) found C–SB–SG–OCL to possess drier soil conditions than the C–OCL–SG–SB sequence throughout the growing season during years with corn due to spring regrowth of clover before planting, resulting in a reduction in aboveground biomass production. Soybean had a positive effect on grain N uptake when included in crop sequences due to greater levels of N in its grain (average soybean grain N

Table 2. Treatment averages (1983–1998) of indicators representing agroecosystem functions. Least significant differences at $P < 0.05$ are included for significant interactions.

Crop sequence†	N rate‡ ZERO	LOW	HIGH	Mean
	Food production			
	Grain yield, Mg ha^{-1}			
CC	3.37	6.22	6.96	5.52 a
C–SB	4.05	4.80	4.79	4.55 b
C–OCL–SG–SB	4.07	4.63	4.65	4.45 b
C–SB–SG–OCL	3.83	4.34	4.50	4.22 c
Mean	3.83 z§	5.00 y	5.22 x	
LSD for interaction = 0.25				
	Grain N uptake, kg ha^{-1}			
CC	30.6	78.2	100.8	69.9 d
C–SB	105.6	118.0	124.8	116.2 a
C–OCL–SG–SB	82.5	99.7	106.6	96.3 b
C–SB–SG–OCL	79.3	93.1	103.0	91.8 c
Mean	74.5 z	97.3 y	108.8 x	
LSD for interaction = 4.0				
	Raw materials production			
	Stover yield, Mg ha^{-1}			
CC	3.98	5.65	6.41	5.35 a
C–SB	4.45	4.94	5.02	4.80 c
C–OCL–SG–SB	4.67	5.25	5.41	5.11 b
C–SB–SG–OCL	4.55	4.97	5.24	4.92 c
Mean	4.41 z	5.21 y	5.52 x	
LSD for interaction = 0.23				
	Stover N uptake, kg ha^{-1}			
CC	16.8	36.5	56.0	36.4 c
C–SB	25.2	34.5	40.3	33.4 d
C–OCL–SG–SB	32.2	45.2	52.9	43.5 a
C–SB–SG–OCL	30.7	40.5	50.7	40.6 b
Mean	26.2 z	39.2 y	50.0 x	
LSD for interaction = 2.6				
	Nutrient cycling			
	Residual soil NO_3–N (0–183 cm), kg ha^{-1}			
CC	47	58	154	86
C–SB	58	64	110	77
C–OCL–SG–SB	58	66	111	78
C–SB–SG–OCL	50	65	100	72
Mean	53 z	63 y	119 x	
LSD for interaction = 16				
	Soil pH (0–30.5 cm), $-\log(H^+)$			
CC	6.57	6.53	6.18	6.43
C–SB	6.56	6.46	6.41	6.48
C–OCL–SG–SB	6.53	6.52	6.45	6.50
C–SB–SG–OCL	6.53	6.44	6.38	6.45
Mean	6.55 x	6.49 x	6.36 y	
LSD for interaction = 0.15				
	Greenhouse gas regulation			
	Soil organic C (0–30.5 cm), Mg ha^{-1}			
CC	46.9	48.8	48.4	48.0
C–SB	51.8	52.2	51.0	51.7
C–OCL–SG–SB	55.7	54.4	55.1	55.1
C–SB–SG–OCL	53.7	52.4	53.9	53.3
Mean	52.0	52.0	52.1	
	Early-spring soil NO_3–N (0–7.6 cm), kg ha^{-1}			
CC	4	7	13	8
C–SB	5	6	8	6
C–OCL–SG–SB	6	7	10	8
C–SB–SG–OCL	6	6	8	7
Mean	5 z	7 y	10 x	
LSD for interaction = 2				

† CC, continuous corn; C-SB = corn soybean; C-OCL-SG-SB, corn-oat+clover-sorghum-soybean; C-SB-SG-OCL, corn-soybean-sorghum-oat+clover.
‡ ZERO, LOW, and HIGH N rates represent 0, 90, and 180 kg N ha^{-1} for corn and grain sorghum and 0, 34, and 68 kg N ha^{-1} for soybean and oat+clover.
§ Values for main effects followed by the same letter within a column (a,b,c,d) or row (x,y,z) are not significantly different at $P < 0.05$.

content = 61.2 vs. 16.1 g kg^{-1} for average of other crops; data not shown). Stover N uptake in the 4-yr sequences was bolstered by sorghum, which possessed the greatest stover N content among the four crops (10.0 g kg^{-1}). Conversely, low stover N content in corn (6.4 g kg^{-1}) negatively affected stover N uptake in CC and C–SB.

Treatment Effects on Agroecosystem Performance

Based on the scoring method used, differences among treatments were observed in agroecosystem performance for the 1983–1998 time period (Table 3). Scaled agroecosystem performance scores ranged from 66.6 to 77.3 with a LSD of 2.2 ($P < 0.05$). Treatments with the highest agroecosystem performance scores that were not significantly different included C–OCL–SG–SB/LOW (77.3), C–SB/LOW (76.9), CC/LOW (76.7), CC/HIGH (76.6), and C–SB–SG–OCL/LOW (75.3), demonstrating that the two 4-yr crop sequence treatments performed similarly to C–SB/LOW, CC/LOW, and CC/HIGH, which are common management practices in the western Corn Belt. Nitrogen fertilization significantly increased agroecosystem performance scores between the ZERO and LOW N rates for all crop sequences except C–SB–SG–OCL. Overall scores peaked at the LOW N rate within each crop sequence, however, indicating the negative effect of N fertilization on agroecosystem performance above that level.

Owing to the additive nature of the scoring method, trends in agroecosystem functions and the indicators characterizing them affected overall performance scores. Food and raw materials production functions increased with increasing N rate within each crop sequence, whereas scores for nutrient cycling and greenhouse gas regulation functions did the opposite (Table 3). Average scores for the production functions increased more between the ZERO and LOW N rates (0.35 for food production; 0.36 for raw materials production) than between the LOW and HIGH N rates (0.12 for food production; 0.24 for raw materials production). Conversely, average scores for the nutrient cycling function decreased less between the ZERO and LOW N rates (0.15) than between the LOW and HIGH N rates (0.33). Average changes in greenhouse gas regulation scores between N rates were about the same (0.19 between the ZERO and LOW N rates; 0.17 between LOW and HIGH N rates).

Within N rates, scores for production functions varied based on the crop sequence (Table 3). At the ZERO and LOW N rates, C–SB possessed the highest food production scores while C–OCL–SG–SB had the highest raw materials production scores among the four crop sequences. At the HIGH N rate, CC possessed the highest scores for both the food and raw materials production functions. Crop sequence affected the range of scores between ZERO and HIGH N rates. In general, presence of leguminous crops in rotation tended to narrow the range of scores observed. This trend was especially evident in the nutrient cycling and greenhouse gas regulation functions where CC possessed the highest and lowest scores among crop sequences.

As expected, scores for food and raw materials production functions were highly correlated ($r = 0.77$; $P < 0.0001$), as were scores for nutrient cycling and greenhouse gas regulation functions ($r = 0.64$; $P < 0.0001$). All other correlations between functions were negative (food production vs. nutrient cycling, $r = -0.68$; food production vs. greenhouse gas regulation, $r = -0.67$; raw materials production vs. nutrient cycling, $r = -0.77$; raw materials production vs. greenhouse gas regulation, $r = -0.75$), demonstrating the opposing nature of production- and environmental protection–related agroecosystem functions for the treatments evaluated in the procedure.

Table 3. Agroecosystem performance scores for treatments over 1983–1998. Scores are shown for individual indicators, agroecosystem functions, and total performance (not scaled and scaled to 100).

Sequence and N rate†	Indicators‡								Agroecosystem functions§				Agroecosystem performance scores	
	GYD	GN	SYD	SN	RSN	PH	SOC	SSN	FP	RMP	NC	GGR	Not scaled	Scaled to 100
CC														
ZERO	0.49	0.25	0.62	0.30	0.93	0.94	0.80	1.00	0.74	0.92	1.87	1.80	5.33	66.6
LOW	0.90	0.62	0.88	0.66	0.76	0.93	0.84	0.55	1.52	1.54	1.69	1.39	6.14	76.7
HIGH	1.00	0.81	1.00	1.00	0.28	0.88	0.83	0.34	1.81	2.00	1.16	1.17	6.14	76.6
CSB														
ZERO	0.58	0.85	0.69	0.45	0.76	0.94	0.89	0.77	1.43	1.14	1.70	1.66	5.93	74.1
LOW	0.69	0.95	0.77	0.62	0.67	0.92	0.90	0.64	1.64	1.39	1.59	1.54	6.16	76.9
HIGH	0.69	1.00	0.79	0.71	0.41	0.92	0.88	0.52	1.69	1.50	1.33	1.40	5.92	73.9
C–OCL–SG–SB														
ZERO	0.59	0.66	0.73	0.57	0.76	0.93	0.96	0.68	1.25	1.30	1.69	1.64	5.88	73.5
LOW	0.67	0.80	0.82	0.81	0.66	0.93	0.94	0.56	1.47	1.63	1.59	1.50	6.19	77.3
HIGH	0.67	0.85	0.85	0.94	0.39	0.92	0.94	0.41	1.52	1.79	1.31	1.35	5.97	74.7
C–SB–SG–OCL														
ZERO	0.55	0.64	0.71	0.55	0.87	0.93	0.92	0.73	1.19	1.26	1.80	1.65	5.90	73.7
LOW	0.63	0.74	0.78	0.72	0.68	0.92	0.90	0.66	1.37	1.50	1.60	1.56	6.03	75.3
HIGH	0.65	0.82	0.82	0.90	0.43	0.91	0.93	0.48	1.47	1.72	1.34	1.41	5.94	74.4
LSD¶	0.02	0.03	0.03	0.04	0.14	NS#	NS	0.09	0.06	0.07	0.15	0.09	0.17	2.2

† CC, continuous corn; C-SB, corn-soybean; C-OCL-SG-SB, corn-oat+clover-sorghum-soybean; C-SB-SG-OCL, corn-soybean-sorghum-oat+clover; ZERO, LOW, and HIGH N rates represent 0, 90, and 180 kg N ha^{-1} for corn and grain sorghum and 0, 34, and 68 kg N ha^{-1} for soybean and oat+clover.

‡ GYD, grain yield; GN, grain N uptake; SYD, stover yield; SN, stover N uptake; RSN, residual soil NO_3; PH, soil pH; SOC, soil organic C; SSN, surface soil NO_3.

§ FP, food production; RMP, raw materials production; NC, nutrient cycling; GGR, greenhouse gas regulation.

¶ Least significant difference at $P < 0.05$ given for comparisons across cropping sequences and N rates.

NS, not significant at $P < 0.05$.

Discussion of indicator scores is simplified in that trends among scores were similar to trends observed for untransformed values of each indicator. Accordingly, all indicators were affected by treatments except soil pH and soil organic C. This resulted in the nutrient cycling function being affected primarily by scored values for residual soil NO_3–N. Similarly, the lack of difference among scored values for soil organic C resulted in surface soil NO_3–N having a predominant role in determining the outcome of greenhouse gas regulation scores.

Agroecosystem performance scores increased from 1990 to 1998 in all treatments except CC/ZERO (Fig. 1). Changes in agroecosystem performance scores over time were more pronounced with increasing N rate. Within the ZERO N rate, differences in agroecosystem performance between 1990 and 1994 were significant only for C–SB. However, differences in performance between the same two time periods were significant for all other crop sequences except C–OCL–SG–SB at the LOW N rate. Changes in agroecosystem performance between 1990 and 1998 were significant for all crop sequences.

Within each time period, few differences among crop sequences were observed (Fig. 1). In 1998, CC at the ZERO N rate possessed significantly lower agroecosystem performance than the other sequences while in 1994, CC possessed significantly higher performance than the other crop sequences at the HIGH N rate. Excess available N within the CC/HIGH treatment and above-average precipitation in 1992, 1993, and 1994 combined to boost production from 1991 to 1994, resulting in the dramatic increase in overall performance (precipitation data not shown).

SUMMARY

Management practices that balance multiple functions of agroecosystems enhance agricultural sustainability. Approaches to quantify agroecosystem performance across multiple functions allow agriculturists to determine the relative sustainability of management practices. A simple multiattribute ranking procedure was used to quantify agroecosystem performance for crop sequence and N fertilization treatments in a long-term cropping systems experiment in the western Corn Belt.

After 16 yr of cropping, C–OCL–SG–SB/LOW, C–SB/LOW, CC/LOW and HIGH, and C–SB–SG–OCL/LOW possessed the highest agroecosystem performance scores among the 12 treatments evaluated with the procedure. For the highest-ranking treatments, those fertilized at the LOW N rate attained high performance scores by being highly productive while minimizing negative environmental effects relative to the other treatments. The CC/HIGH treatment, however, attained a high agroecosystem performance score solely through its superior capacity to be highly productive; scores for the two environmental quality–related functions (nutrient cycling and greenhouse gas regulation) for CC/HIGH were the lowest among all treatments.

Nitrogen fertilization significantly increased agroecosystem performance between ZERO and LOW N rate treatments but had a negative effect on performance

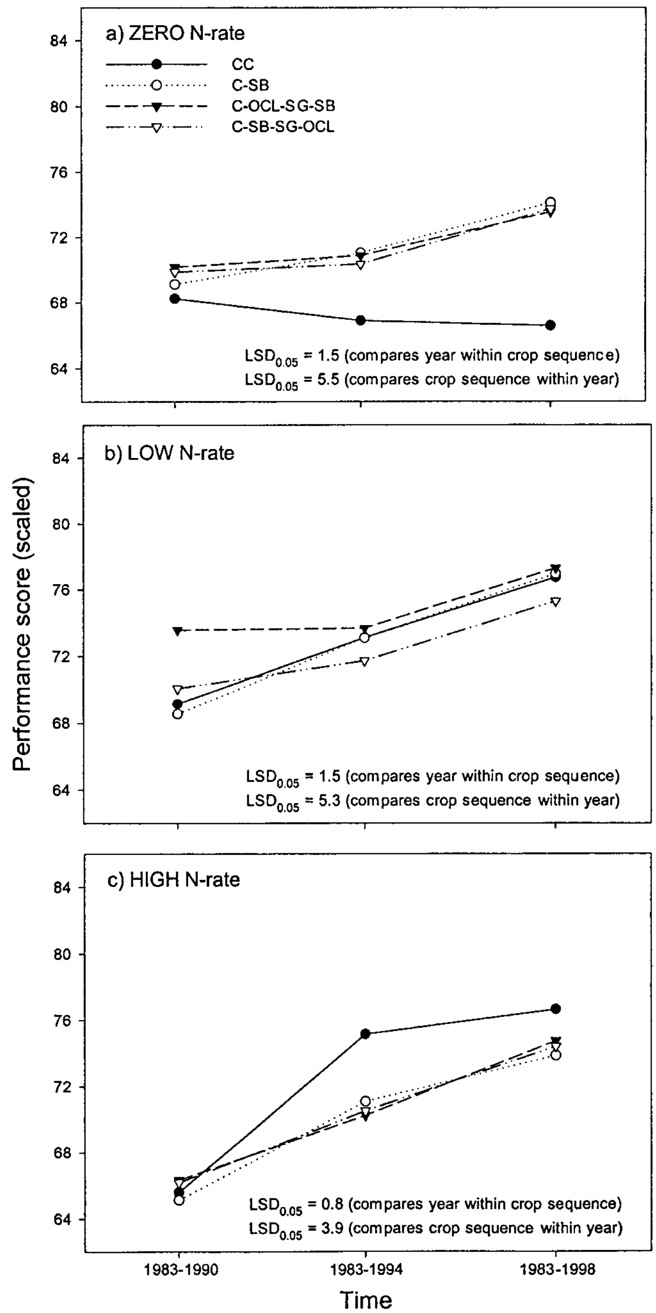

Fig. 1. Performance scores (scaled to 100) from 1983–1990, 1983–1994, and 1983–1998 for four crop sequences organized by N rate. ZERO, LOW, and HIGH N rates represent 0, 90, and 180 kg N ha^{-1} for corn and grain sorghum and 0, 34, and 68 kg N ha^{-1} for soybean and oat + clover. CC, continuous corn; C–SB, corn–soybean; C–OCL–SG–SB, corn–oat + clover–sorghum–soybean; C–SB–SG–OCL, corn–soybean–sorghum–oat + clover.

above that level. Correlations between scores for food production, raw materials production, nutrient cycling, and greenhouse gas regulation functions indicated the opposing nature of production- and environmental protection–related components for these cropping systems, underscoring the importance of employing management practices that balance multiple functions of agroecosystems. Agroecosystem performance scores increased over time for all treatments except for CC/ZERO, and changes in scores over time were more pronounced with increasing N rate.

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